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COMPARISON OF THE HYADES, COMA, AND PLEIADES CLUSTERS BASED ON PHOTOELECTRIC u,v,b,y and Hβ PHOTOMETRY*

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On the basis of photoelectric U,B,V photometry, Johnson and Knuckles (1955) carried out a comparison of the distribution in the (U-B) vs. (B-V) diagram of members of the Hyades and Coma clusters. They concluded that the Coma cluster members show an ultraviolet excess relative to the Hyades stars that amounts to $0^{m}.035$ for (B-V) around $+0^{m}.4$. They suggested that this photometric effect might be caused by a difference in the chemical composition of members of the two clusters.

Strömgren (1958) in the Stellar Populations volume, with the use of his original metallic-line index, also showed that the Hyades and Coma cluster stars are different. The difference in both cases suggests that the metal/hydrogen ratio is lower for the Coma cluster stars than for the Hyades stars.

Since both of these clusters are young Population I and are of approximately the same age, it is important to investigate further the question of differences in chemical composition. For the color-index range (B-V) = $0^{m}.4$ to $0^{m}.6$ the main sequence stars in the two clusters are practically unevolved, i.e. they are very close to the zero-age line defined by the beginning of the hydrogen burning phase. For this color-index range, the indices (b-y), m_1, and c_1 of photoelectric u,v,b,y photometry, and the index β of photoelectric Hβ photometry, should yield significant information

regarding the chemical composition of the cluster stars.

These photometric systems have been discussed in some detail by Strömgren (1963a,b) and by Crawford (1958,1960).

The comparison of the Hyades and Coma clusters presented here is based on photoelectric u,v,b,y and Hβ photometry of 79 Hyades members and 35 Coma cluster stars, carried out by the authors and Miss Jeannette Mander at the Kitt Peak National Observatory.

We assume that interstellar reddening is negligible for the members of the two clusters, and, since we are comparing stars that are practically unevolved, we must attribute differences found for the Hyades and Coma stars to differences in chemical composition. Comparison of the two clusters is made through an examination of the following relations: c_1 vs. β, (b-y) vs. β, m_1 vs. (b-y) and (u-b) vs. (b-y).

Figure 1 shows the β vs. c_1 relation of the Hyades. The solid line indicates the zero-age main sequence. Figure 2 shows the same relation for Coma. Figure 3 shows the c_1 vs. (b-y) relation for the Hyades and Figure 4 for Coma.

Consider now the (u-b) vs. (b-y) relation. From the photometry of the Hyades stars, we can derive a standard (u-b) vs. (b-y) relation for the (b-y) range in question. The result is given in Table 1. Then for each Coma star with its measured (b-y) we list the(u-b) from the Hyades relation

and the difference Δ (u-b). A positive Δ (u-b), i.e. an ultraviolet excess, is found for all Coma stars in the (b-y) range considered. The average value is $+0\overset{m}{.}061$.

We thus confirm the result obtained by Johnson and Knuckles that the Coma cluster stars have an appreciable ultraviolet excess when compared to the Hyades stars. Since it is known from a comparison of values of Δ (u-b) and Δ (U-B) from metal-poor stars (Strömgren, 1964) that the Δ(u-b) scale is on the average 1.6 times wider than the Δ (U-B) scale for the color-index range in question, we conclude that there is good agreement between the average values of the ultraviolet excess found in the two investigations.

We now turn to the c_1 vs. β relation. Again we derive a standard relation from the Hyades stars. Table 2 shows the normal points and the mean relation. Table 3 derives Δc_1 values for individual Coma stars. The average value is $-0\overset{m}{.}027$; again an ultraviolet excess is indicated. Analogous treatment of the indices m_1 and (b-y) gives an average value of Δm_1 of $+0\overset{m}{.}010$ for the Coma stars relative to a standard relation defined by the Hyades stars. Finally we examine in similar fashion the (b-y) vs. β relation given in Table 3. Here is is found that the average difference between (b-y) for equal β for the Coma and Hyades stars amounts to $-0\overset{m}{.}007$.

The comparison of the results of the photoelectric u,v,b,y

and Hβ photometry of Hyades and Coma cluster stars thus clearly shows that the member stars differ in chemical composition. We turn now to a discussion of the problem of quantitative determination of the differences in question. On general grounds we would expect that the observed photometric effects are largely due to differences in the helium/hydrogen ratio and of the heavy-element content to the hydrogen content. Such differences affect the internal constitution of the stars, hence their radii and luminosities, and therefore also the effective temperature and surface gravity that determine the properties of the atmospheres. Thus the differences in chemical composition influence the emitted spectrum both by the internal constitution and through the direct effect of the absorption line spectrum, and in this connection the blanketing effect.

For B and A stars the changes in the emitted spectrum, and in particular the changes of specified photometric indices, with chemical composition can be computed quantitatively through the combination of results obtained in stellar-interior and stellar-atmosphere calculations (cf. e.g. Strömgren (1964) and Kelsall and Strömgren (1964)). For the color-index range in question the situation is less favorable. Neither the stellar-interior nor the stellar-atmosphere calculations available at the present time have the accuracy required for our purpose. However, the goal is well-defined, and it is expected

that the situation will improve a good deal during the next few years.

In view of this uncertainty, we limit our discussion to comments on two questions. Consider the values of Δ (u-b) and $\Delta\ m_1$ found above from the photometric comparison in the Hyades and Coma cluster stars. From studies based on a comparison of the Hyades with metal-poor stars, a ratio of Δ (u-b) to $\Delta\ m_1$ of about three has been found. It would therefore appear that the relation between Δ (u-b) and $\Delta\ m_1$ is not linear, since the ratio is about 6 in the Hyades-Coma comparison, where the difference in metal content is considerably smaller than in the case of the metal-poor stars. For metal-contents that do not differ strongly from that of the Hyades, Δ (u-b) is thus an index of metal content that is much more sensitive than $\Delta\ m_1$. It should be emphasized, however, that precisely when the aim is the evaluation of relatively small differences in metal content, the (u-b)-method can be used safely only when independent knowledge of the difference in absolute magnitude is available, for (u-b) is sensitive to absolute magnitude. In our discussion of the unevolved Hyades and Coma cluster stars this, however, is the case.

Although the stellar-interior and stellar-atmosphere calculations are not very accurate for the late-F and early-G stars considered here, it is still possible to interpret the

phenomenon of the relatively high sensitivity of Δ (u-b) to changes in metal content in the range of metal contents characterized by small variation from the Hyades value. Suppose that the relative metal content is reduced by a small amount from the Hyades value. This reduction influences the radius and the luminosity, and the value of the surface gravity for a given effective temperature. The change in surface gravity goes in the direction that gives a smaller Balmer discontinuity, and hence an ultraviolet excess is produced, which is added to the effect of reduced absorption-line blanketing in the ultraviolet, and hence Δ (u-b) varies relatively strongly with the metal content. For larger reductions of the metal content, the Δ (u-b) produced via the change in surface gravity is less pronounced.

The quantities Δ (u-b), $\Delta\ c_1$, and $\Delta\ m_1$ derived from the photometry are indicators of the metal/hydrogen ratio. We can now ask the question, Is it possible in principle to derive both the change in the metal/hydrogen ratio and in the helium/hydrogen ratio? In the case of the Hyades-Coma comparison the outlook is not promising, for here we do not know from observation the difference in absolute magnitude on the zero-age line for equal effective temperature. Consider, however, the comparison of Hyades stars and Population I field stars of relatively large trigonometric parallaxes,

again in the color-index range (B-V) = $+0\overset{m}{.}4$ to $0\overset{m}{.}6$. We calibrate the c_1 vs. (b-y) diagram for field stars in terms of absolute magnitude, M_V . Next we find M_V values for the Hyades stars from photometrically determined c_1 and (b-y) values. Finally, we compare the photometric values with the M_V values derived from the cluster motion (cf. van Bueren (1952)). The average residual turns out to be small, $0\overset{m}{.}2$, and in view of possible systematic errors in the trigonometric and cluster parallaxes, we must admit that this residual might not be significant. (The need for high quality astrometric data is evident.) However, if we accept this value, we arrive at the conclusion that the helium/hydrogen ratio is higher for the Hyades than for the average of Population I field stars. The effect goes in the same direction as that derived by Eggen (1963) from a study of visual-binary masses for Hyades stars. However, the effect indicated by the M_V residual given above is smaller, and it appears safe to conclude from our discussion that there is no very large difference in the helium/hydrogen ratio for the Hyades stars, as compared to the average Population I field star.

In discussing the (b-y) vs. β relation for unevolved stars, we found that the difference in (b-y) for given β caused by the difference in metal content between the Hyades and the Coma cluster stars is small. This result means that the

actua variation of the metal/hydrogen ratio found among young Population I stars does not seriously affect the determination of (b-y) from β for unevolved stars. Hence we have here a reliable method for the determination of intrinsic colors and color excesses. We have applied this method to the Pleiades st... in the color range $(B-V) = +0^{m}.4$ to $+0^{m}.6$. Forty-two stars were used and the average excess found was $+0^{m}.035$ in (b-y). This value corresponds to $+0^{m}.050$ in (B-V). The range in E (b-y) is from 0 to $0^{m}.1$. We wish to point out that the average reddening determined in this way agrees very well with that determined from U,B,V, photometry of B-type stars in the Pleiades (Mitchell and Johnson (1957)). This agreement indicates that the adopted $(U-B)_o$ vs. $(B-V)_o$ relation for the B-type stars cannot be much in error. Figure 5 shows the β vs. c_1 relation for the Pleiades, and Figure 6 the c_1 vs. (b-y) relation.

Having determined individual reddenings for the Pleiades stars, we can apply reductions for interstellar reddening to the indices (u-b), c_1, and m_1, and thereafter carry out a comparison between the Pleiades and the Hyades analogous to that made between the Coma cluster and the Hyades. There is at present some uncertainty in the dependence of interstellar extinction upon wavelength. However, an analysis carried out on the basis of the reddening-law derived by Whitford (1958)

leads to the conclusion that the Pleiades and the Hyades have very nearly the same metal/hydrogen ratio.

The data for all three of these clusters will be presented in detail and discussed further in separate publications.

Table 1

The (u-b), (b-y) Relation for the Unevolved Hyades and Coma Stars

Unevolved Hyades Relation

(b-y)	(u-b)
$0^m.310$	$1^m.366$
.320	1.388
.330	1.410
.340	1.432
.350	1.454
.360	1.476
.370	1.498
.380	1.520

Unevolved Coma

(b-y)	(u-b)	$(u-b)_{Hya}$	Δ(u-b)
$0^m.334$	$1^m.362$	$1^m.419$	$0^m.057$
.327	1.346	1.403	.057
.363	1.401	1.483	.072
.357	1.412	1.469	.057
.379	1.460	1.518	.058
.306	1.315	1.379	.064
.306	1.314	1.379	.065
.344	1.396	1.441	.045
.357	1.374	1.469	.095
.303	1.311	1.351	.040
.369	1.445	1.496	.051
.345	1.378	1.443	.065
.315	1.307	1.377	.070
	13 Stars		0.061

Table 2

The c_1 , β Relation for the Hyades Stars

Hyades

Group	n	(b-y)	c_1	β	m_1
A	8	$0^m.276$	$0^m.472$	$2^m.677$	$0^m.170$
B	8	.292	.443	2.661	.174
C	9	.329	.399	2.638	.179
D	6	.348	.373	2.626	.185
E	7	.358	.362	2.622	.193
F	5	.375	.327	2.604	.212

$$c = 0.319 + 2.03\ (\beta - 2.600)$$

$$(b-y) = 0.385 - 1.46\ (\beta - 2.600)$$

Mean Relation

β	c_1	(b-y)
$2^m.600$	$0^m.319$	$0^m.385$
2.610	.339	.370
2.620	.360	.356
2.630	.380	.341
2.640	.400	.327
2.650	.420	.312
2.660	.441	.297
2.670	.461	.283
2.680	.481	.268
2.690	.502	.254

Table 3

The c_1 , β, (b-y) Relations for the Hyades and Coma Stars

Coma

Group	n	(b-y)	c_1	β	c_1 (Hya)	Δc_1	(b-y)	Δ(b-y)
		m	m	m	m	m	m	m
A	4	0.282	0.434	2.672	0.465	-0.031	0.280	+0.002
B	6	.321	.365	2.635	.390	-0.025	.334	-0.013
C	6	.362	.310	2.608	.335	-0.025	.373	-0.011
						-0.027		-0.007

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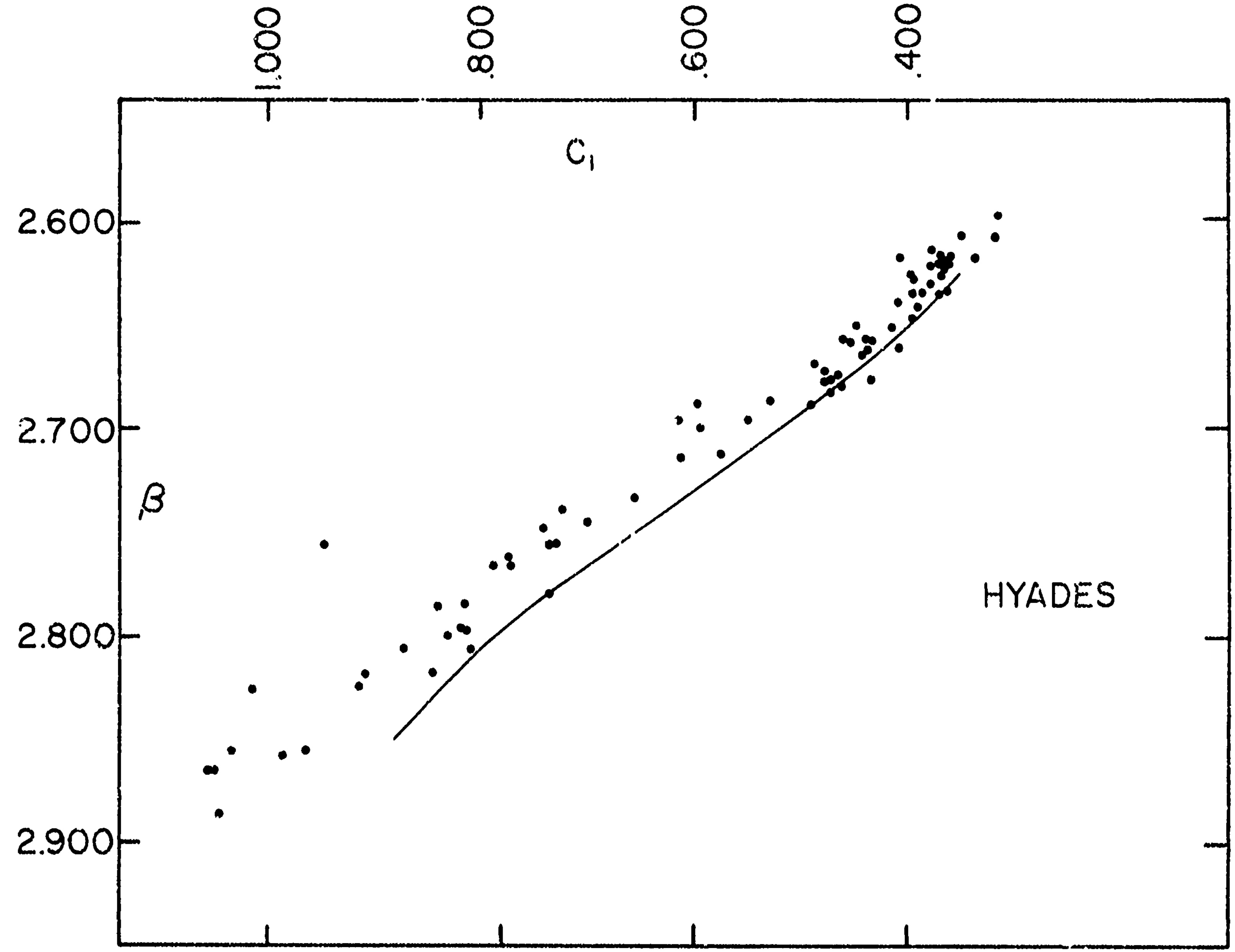

Figure 1 The β vs c_1 relation for Hyades stars. The line is the zero-age main sequence relation.

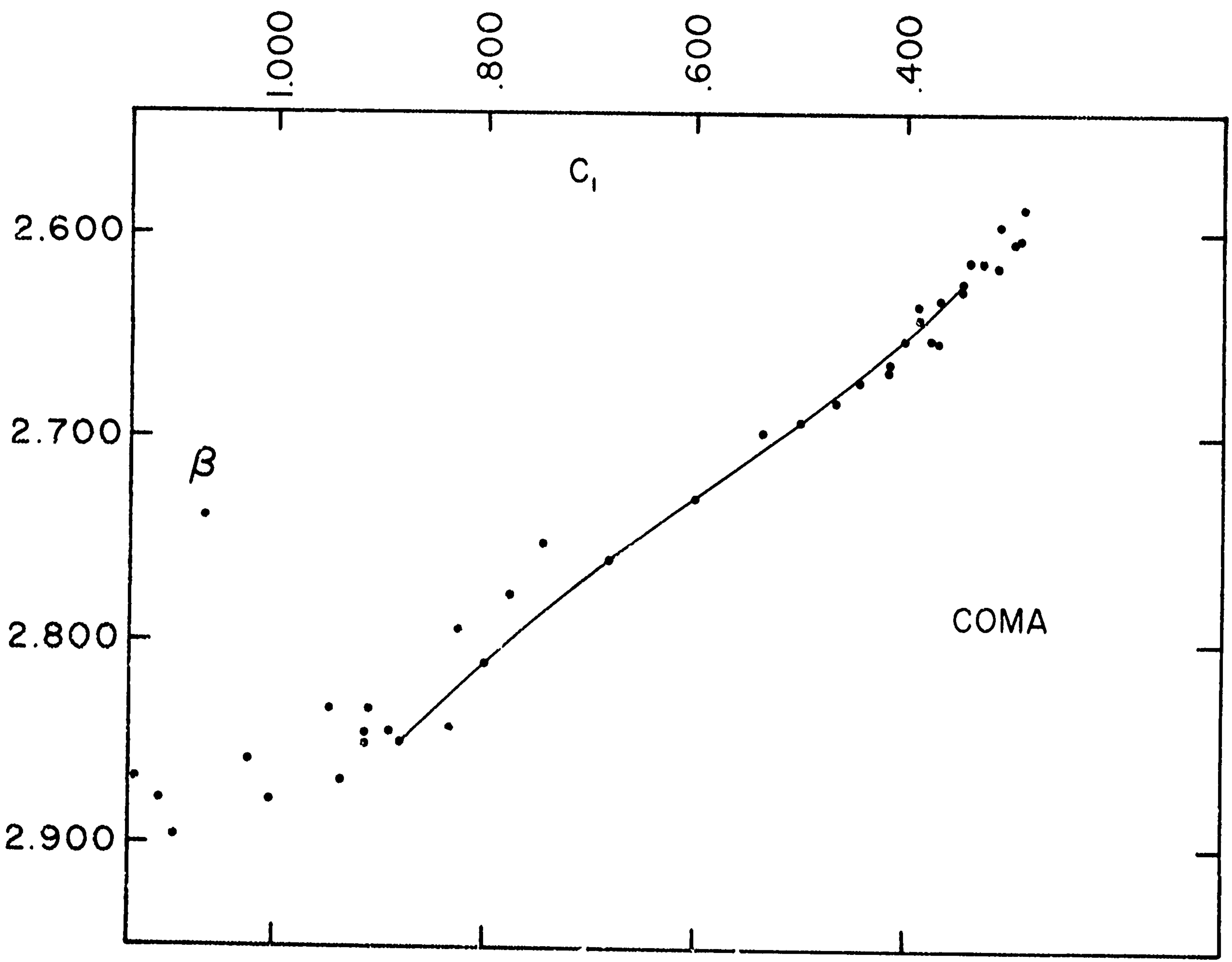

Figure 2 The β vs c_1 relation for Coma stars.

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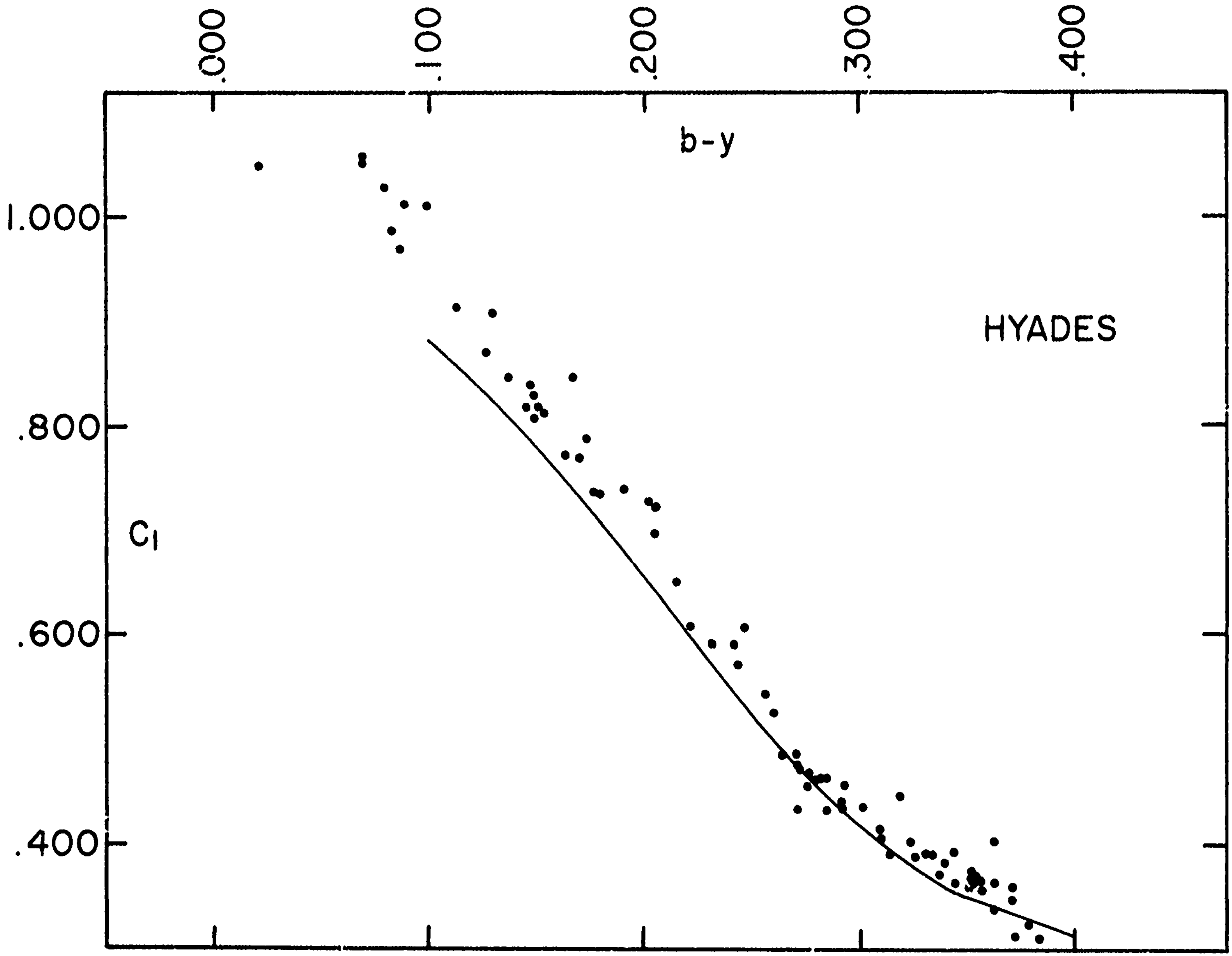

Figure 3 The c_1 vs (b-y) relation for the Hyades stars.

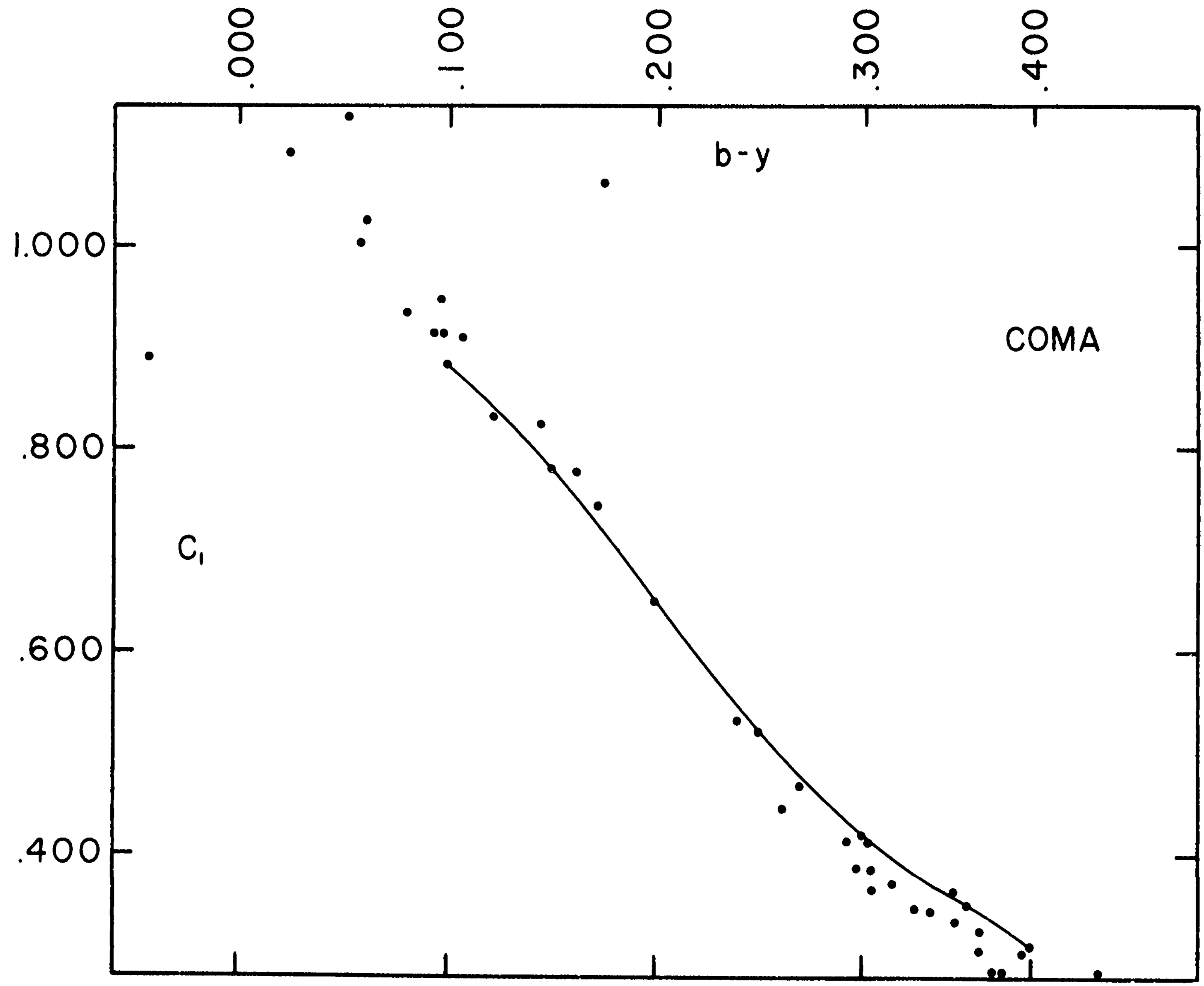

Figure 4 The c_1 vs (b-y) relation for Coma stars.

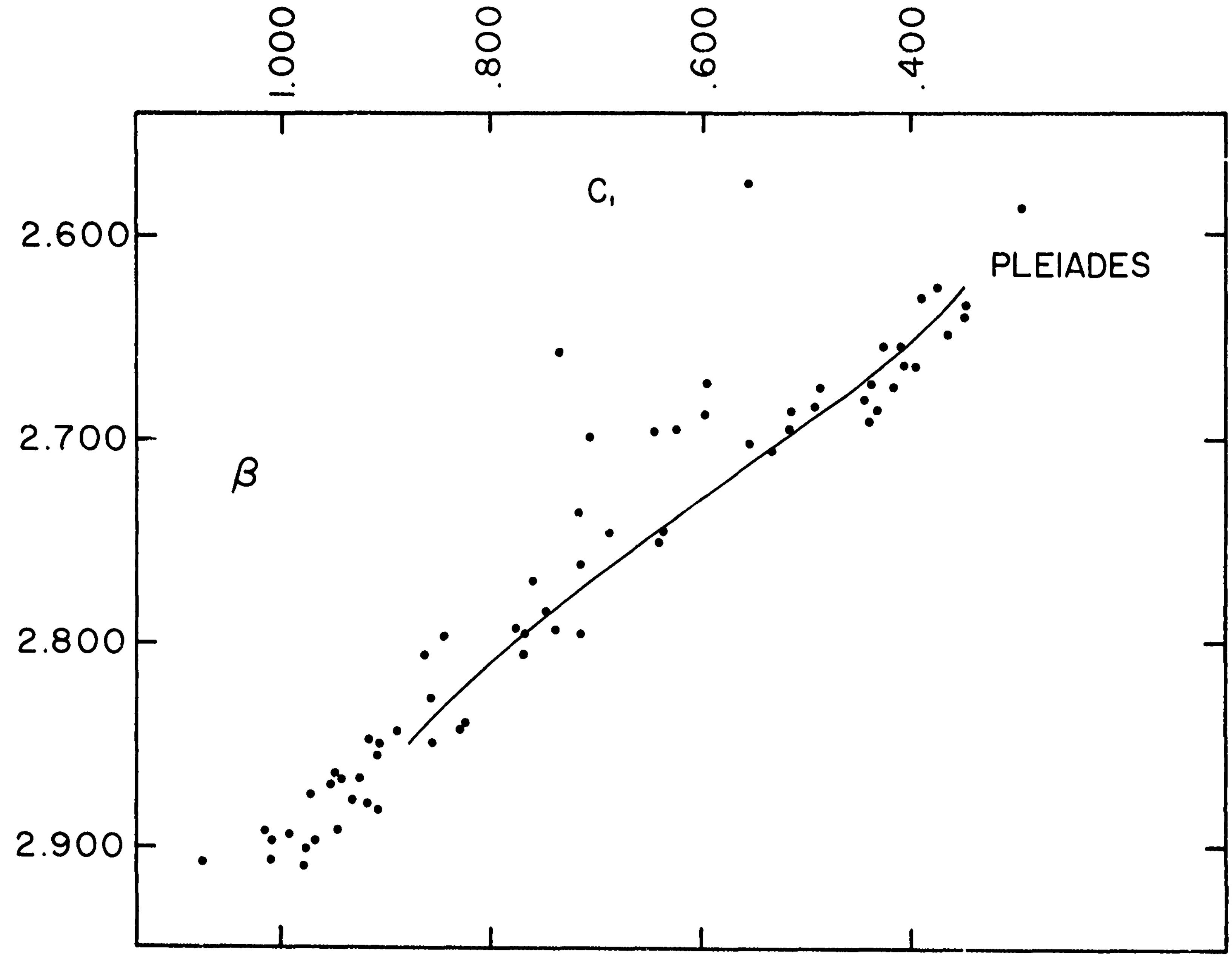

Figure 5 The β vs c_1 relation for the Pleiades stars.

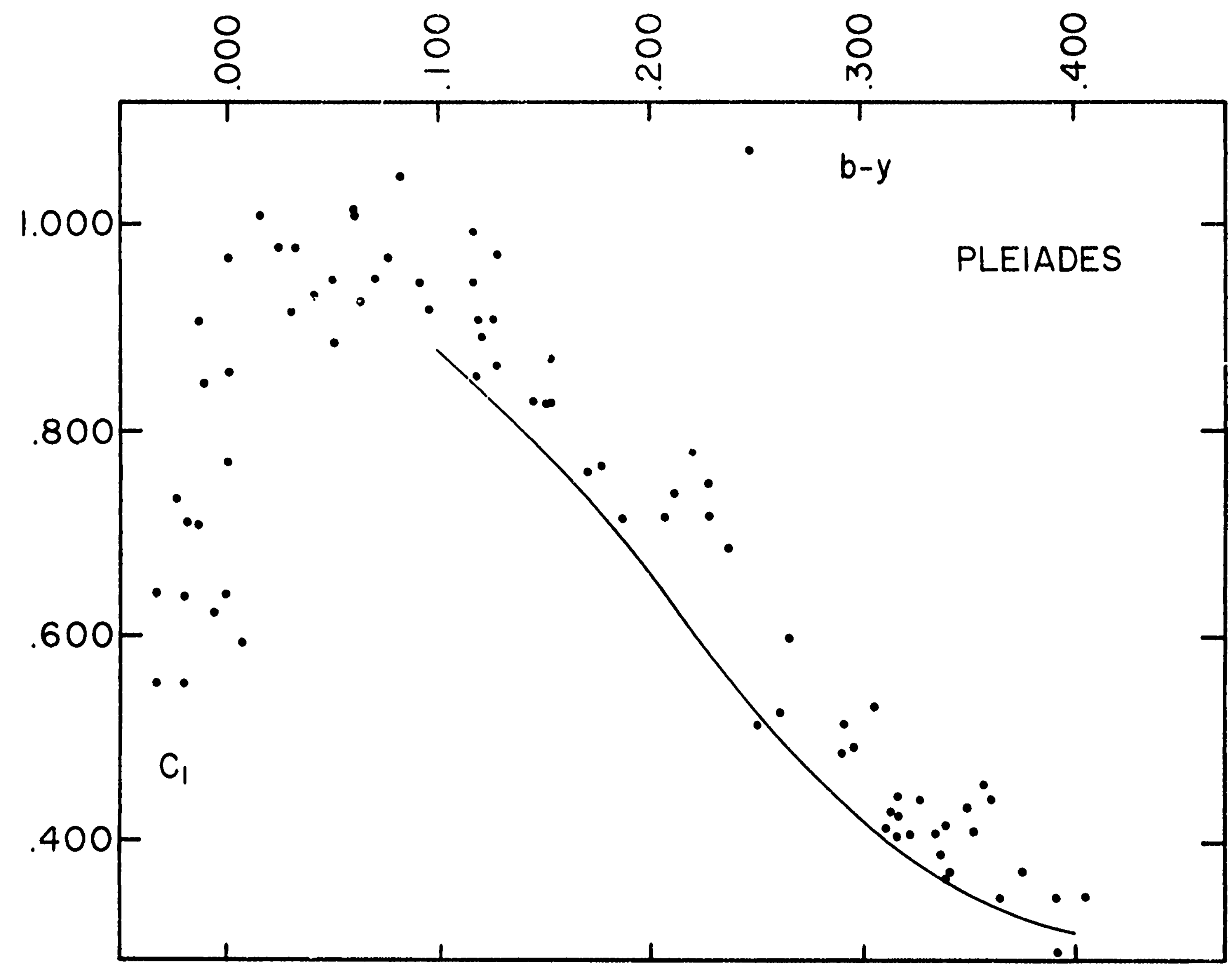

Figure 6 The c_1 vs (b-y) relation for the Pleiades stars.